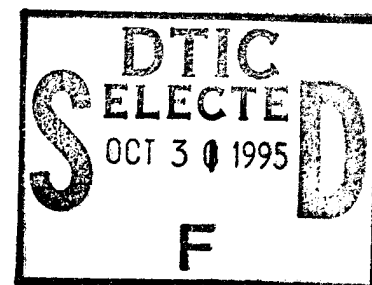


FINAL TECHNICAL REPORT  
ONR GRANT # N00014-90-J-1132



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## GOALS

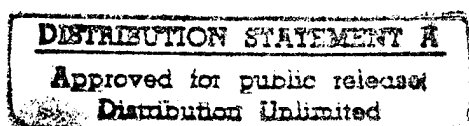
We are interested in studying the inherent optical properties (IOP) from a theoretical as well as an experimental perspective. Radiative transfer theories linking the apparent optical properties (AOP) to the IOP will be further developed and tested. The IOP form the link between the biogeochemical nature of the suspended and dissolved materials and radiative transfer. This link must be investigated both theoretically and experimentally. The ultimate goal of this program is to be able to predict radiative transfer in the oceans given the biogeochemical nature of the suspended and dissolved materials and their distribution.

## OBJECTIVES

Real progress in Optical Oceanography requires the ability to verify models in a variety of optical water types. We therefore directed our efforts during this grant towards optical closure. Optical closure is the simultaneous verification of optical relationships and optical instrumentation. The end result will be knowledge of the accuracy with which inherent and apparent optical properties can be measured, and the testing of a number of fundamental optical relationships, including solutions to the equation of radiative transfer and the relationship of particulate properties and inherent optical properties via Mie theory for three-layered particles.

## TASKS

We carried out studies of the dependence of light absorption by water in the red and infrared parts of the spectrum on the temperature. We continued our theoretical studies of the inherent optical properties of phytoplankton using a three-layered sphere model. We directed a joint program with the University of Miami, San Diego State University, SRI, NOARL and Tetra Tech Optical Oceanography groups to carry out investigations on optical closure. We carried out a field experiment at the David Taylor Research Center, Lake Pend Oreille, Idaho. The field experiments involved the measurement of complete sets of the spectral values of the IOP and AOP from a barge moored in optically deep water. The experiment was carried out in April and May of 1992. Measurements included in situ spectral attenuation, absorption and backscattering coefficients as well as a few observations of the volume scattering coefficient. Spectral scalar and vector irradiance were measured well away from the barge so as to avoid shadow problems. Several radiance profiles were obtained. HPLC pigments and nutrients were determined from bottle samples as well as particle size distributions and spectrophotometric absorption spectra. Significant progress has been made towards the analysis of the data gathered at Lake Pend Oreille, resulting in a number of publications.



## RESULTS

We demonstrated that the absorption of light in the region of 630 to 760 nm is strongly temperature dependent, whereas at the shorter wavelengths temperature dependence is weak ( Pegau and Zaneveld, 1992, 1994 ). In the field 750 nm is thus a poor reference wavelength. Other temperature dependent effects were hinted at around 600 nm and need to be further explored. This also explains a long observed phenomenon of apparent negative absorption around 750 nm in spectrophotometers. This is due to different temperatures of the reference and sample cuvettes. We found very little change in the absorption spectrum of pure water with temperature for wavelengths below 600 nm. There are regions associated with the overtones of the O-H vibrational modes that have higher dependencies on temperature. For wavelengths not associated with an overtone the change is around  $0.00025\text{m}^{-1}/\text{degC}$ . We found the highest temperature dependence in the visible region at 715 nm ( $0.0037\text{m}^{-1}/\text{degC}$ )

Calculations of the inherent optical properties of phytoplankton modeled by three-layered spheres shows that the internal structure of the particles can have a profound influence on the IOP ( Kitchen and Zaneveld, 1992, 1995; Bricaud, Zaneveld and Kitchen, 1992). The absorption coefficient is only weakly influenced, the attenuation coefficient more strongly, and the backscattering can be orders of magnitude higher than for homogeneous spheres. We carried out calculations of the shape of the volume scattering function in the neighborhood of an absorption maximum using Mie theory and three-layered spheres. Variations of the shape of the volume scattering function are generally found to be small and comparable to those of homogeneous spheres, except in the backward direction.

Much of our effort was directed towards the Optical Closure field experiment. We carried out calculations of the closure of the IOP (Pegau, Zaneveld and Voss, 1995). The absorption and attenuation coefficients were measured independently in situ and the scattering coefficient was calculated from GASM data. Ignoring the first degree of the scattering function in the extrapolation from the GASM data, we found the classical  $a+b=c$  equation to be correct to within the error margins of the instruments.

We compared seven methods for the determination of the absorption coefficient (Pegau et al. 1995). The results at 532 nm were very good with all determinations falling within approx. 10% of each other. The errors increased in the blue part of the spectrum, probably due to calibration problems. The determinations via Gershun's equation and the isotropic point source were very similar to those from the reflecting tube. This shows that in this case the volume of the measured water played no role, i.e. the absorption coefficients are independent of scale. During this experiment the in situ reflective tube spectral absorption meter was tested for the first time (Zaneveld et al., 1992; Moore et al., 1992).

We carried out theoretical work on the remotely sensed reflectance (Zaneveld, 1995). From the equation of radiative transfer we derived a series of expressions for the remotely sensed reflectance with successively greater approximations. The more complete expressions will be needed in turbid coastal waters and the simpler ones can be used in case 1 waters.

At the request of Dr R.S. Spinrad of ONR, we hosted Prof. K.S. Shifrin, Director of the Laboratory of Oceanic Optics of the Institute of Oceanology of the Academy of Sciences of the U.S.S.R. He carried out work on the inversion of light scattering data to obtain particulate properties (Shifrin and Pegau, 1992) and on the optics of the atmospheric boundary layer just above the ocean.

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REFERENCES (Significant portions of the research for the publications listed below was carried out under the auspices of this grant)

Kitchen, J. C. and J. R. V. Zaneveld. 1992: A Three-Layered Sphere Model of the Optical Properties of Phytoplankton, *Limnol. Oceanogr.* **37**, 1680-1690

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Pegau, W.S., J.R.V. Zaneveld, and K.J. Voss 1995: Towards closure of the inherent optical properties. Accepted for publication in *J. Geophys. Res.*

Pegau, W.S., J. Cleveland, D. Kennedy, J.L. Mueller, R.A. Maffione, C. Trees, K.J. Voss, A. Weidemann, W. Wells, and J.R.V. Zaneveld 1995: A comparison of methods for the measurement of the absorption coefficient in natural waters. Accepted for publication in *J. Geophys. Res.*

## INVITED AND CONTRIBUTED PAPERS AT CONFERENCES

### Invited

Zaneveld, J.R.V. 1992: New observations of in situ absorption and backscattering: consequences for remote sensing models. ASLO 92, Santa Fe, February 1992.

Itturiaga, R., B.H.Jones, R.C.Smith and J.R.V.Zaneveld. 1992: Fluorescent measurements of the distribution of picoplanktonic cyanobacteria in the North Atlantic Ocean. ASLO 92, Santa Fe, February 1992.

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Zaneveld, J.R.V. and W.S.Pegau. 1993: Overview of the optical closure experiment at Lake Pend Oreille. Optical Society of America Annual Meeting.

### Contributed

Zaneveld, J. R. V., J. C. Kitchen, A. Bricaud and C.C.Moore. 1992: Analysis of In Situ Spectral Absorption Meter Data, Ocean Optics XI, SPIE, San Diego, July 1992.

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February 6, 1995

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ONR Grant# N00014-90-J-1132  
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Professor

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